

## **Historic, Archive Document**

Do not assume content reflects current scientific knowledge, policies, or practices.



1971

A99.9 F7632US

FOREST SERVICE

U.S. DEPARTMENT OF AGRICULTURE

## ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

## Evaporation from Bare Soil as Affected by Texture and Temperature

Ralph E. Campbell<sup>1</sup>

Evaporation of water under several drying conditions was studied in six soils from the semiarid upper Rio Puerco drainage of New Mexico. Evaporation from initially saturated soils exposed to the atmosphere was 0.33 inch per day at 90°F. and 0.22 inch per day at 60°F. Sandy soils lost half of their moisture in 5 and 7 days at 90° and 60°F., respectively, compared to 8 and 15 days for clay soils under similar conditions. After rapid initial moisture loss, the dried surface of sandy soils acted as a barrier to further moisture loss.

KEY WORDS: Soil moisture, soil temperature

Inadequate soil moisture presents one of the most critical management problems in watershed areas of the Southwest. In the upper Rio Puerco watershed, the season of maximum precipitation is also the season of maximum temperature and evaporative stress. Attempts to reseed sparsely vegetated lands to grasses may succeed only if soil moisture is adequate. One of the important initial steps in evaluating sites for range reseeding or establishing vegetation for erosion control is to understand the patterns of evaporation from various soils following storm events.

Reported here is a study of comparative drying rates among soils of differing texture. The soils were held at two constant temperatures and dried from saturation in early summer and early fall. Evaporation rates were also compared on these

soils when they were supplied with small increments of water, simulating light rain showers.

Limitations of environmental control during these studies reduced some of the comparisons to an observational basis, so conclusions from some aspects of the study are somewhat subjective.

Many studies have related the drying of bare soils to the environmental factors which influence drying. Moisture movement in the soil and, subsequently, evaporation from the soil, are functions of soil moisture content, soil moisture potential gradients, temperature gradients, diffusivity, and conductivity, as well as evaporative stress factors above the soil surface. Evaporation from soil under constant evaporative stress can be approximately described by a nonlinear partial differential equation with the aid of computers (Hanks et al. 1969), but with the natural variability in soils and the variety of evaporation stress conditions encountered in the field, an explicit mathematical expression of evaporation is impractical if not presently impossible. Thus when describing the evaporation from a particular set of soils or making comparisons among them, it is still expedient to determine evaporative losses experimentally.

<sup>1</sup>Soil Scientist, located at Albuquerque in cooperation with the University of New Mexico; station's central headquarters maintained at Fort Collins in cooperation with Colorado State University. Research reported here was conducted in cooperation with the Bureau of Land Management, U. S. Dep. of the Interior.

Table 1.--Textural classification, particle size distribution, and moisture content at saturation, -1/3 and -15 bar matric potential of six soils from the Cabezon area, upper Rio Puerco, New Mexico

Two-letter map symbol	Soil series, texture	Particle size distribution			Moisture content		
		Sand	Silt	Clay	Saturation	-1/3 bar potential	-15 bar potential
		- - - - -	- - - - -	- - - - -	-Percent-	- - - - -	- - - - -
Br	Berent loamy fine sand	77	11	12	29.9	8.7	4.0
Pf	Penistaja fine sandy loam	45	43	12	32.0	8.2	3.7
Au	Alluvial land (sandy loam)	47	36	17	45.2	22.2	9.5
Ps	Persayo silt	17	82	1	47.0	25.2	14.9
Cg	Christianburg (clay loam)	29	34	37	45.0	24.8	10.6
Ng	Navajo clay	2	37	62	61.0	40.4	21.6

The soils used in the study (table 1) were: Berent loamy fine sand, Penistaja fine sandy loam, alluvial land (sandy loam), Persayo silt, Christianburg clay loam, and Navajo clay. All these soils have been correlated, and are described by Folks and Stone (1968). Moisture contents of the six soils at -1/3 and -15 bars matric potential are also shown (table 1).

The study was comprised of three pot experiments. Each is presented here serially, and all are then briefly discussed jointly. Surface soils were air-dried and passed through a 1/4-inch-mesh wire cloth screen to eliminate large clods before being placed in pots.

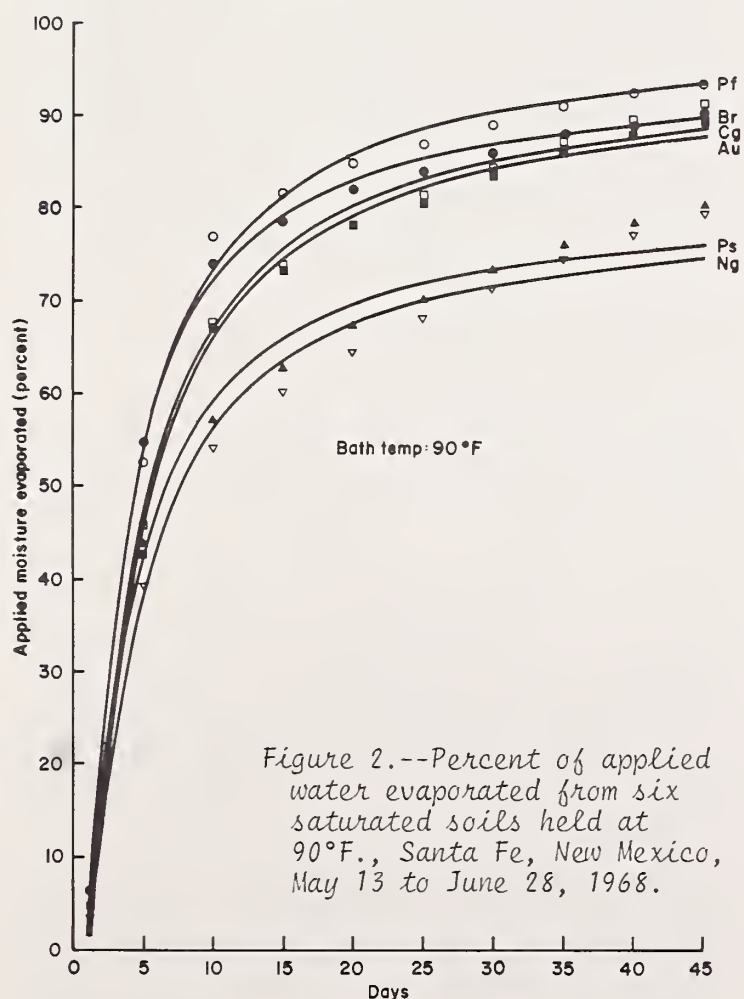
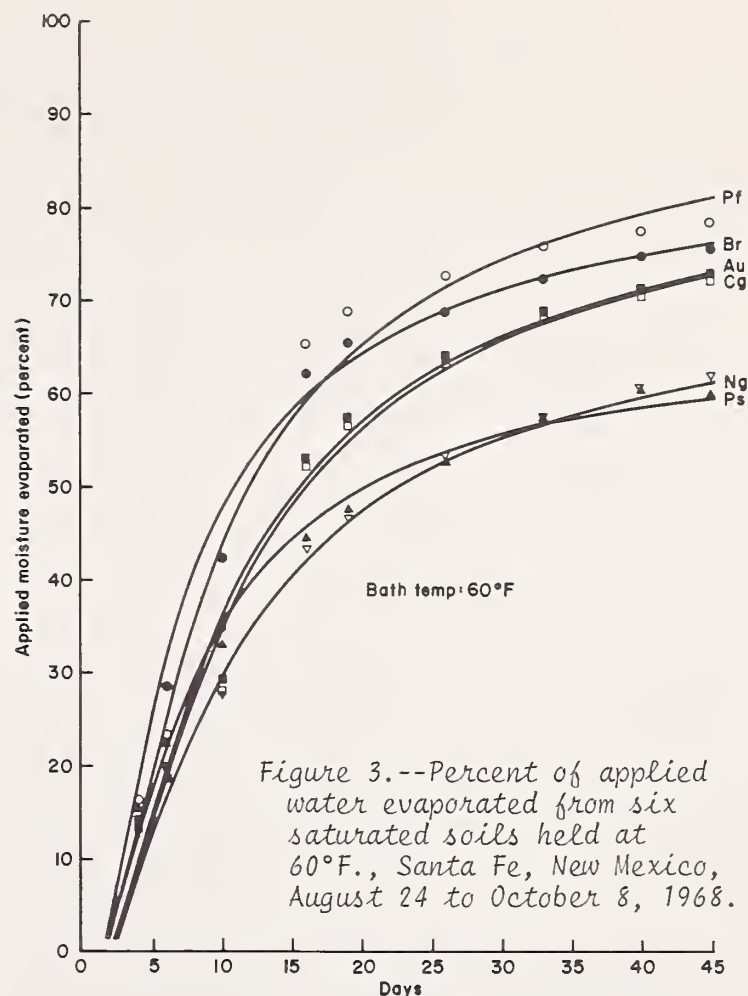
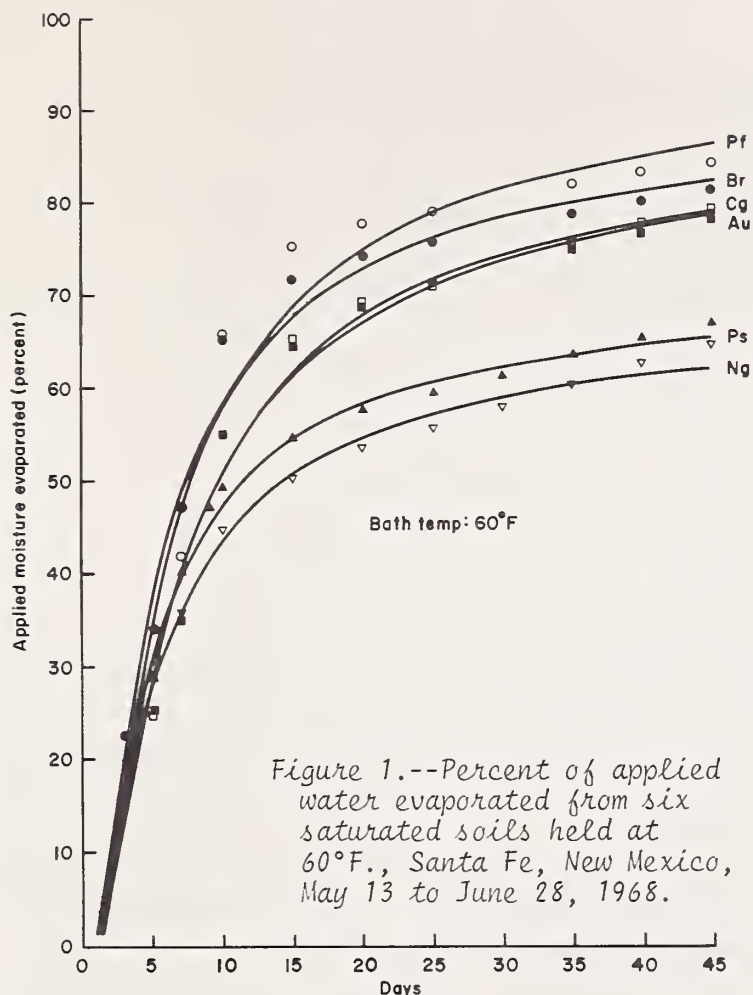
### Santa Fe Experiment

**Procedure.**—The first of the three experiments was conducted in a small green fiberglass-walled shelter at the Forest Service Laboratory at Santa Fe, New Mexico. The six soils were replicated four times in each of two constant-temperature baths. Temperatures were maintained at 60°F. and 90°F.  $\pm 2^\circ$ . The shelter walls around the tanks extended about 4 feet above the top of the pots. The canvas roof was removed except when rain was expected. Air-dried soils were placed in pots 6 inches in diameter and 9 inches deep, lined with a plastic bag. All pots of a given soil were the same weight, filled to 8.5 inches and uniformly packed. Enough water was added to each pot to saturate

the soil at the beginning of each of two drying periods of about 45 days. Evaporation began on May 13, 1968. The second drying, with the 60°F. temperature bath only, began on August 24. Calculations were based on readings made daily for the first 10 days, and at 5-day intervals thereafter.

**Results.**—Evaporation is expressed as percent of applied water used, and is plotted against time (figs. 1-3).

The initial drying rate was rapid and quite uniform, as described by Gardner (1961), but differed significantly among soils. Evaporation was more rapid from the sandy soils than from the clay soil. The differences among soils were greater at 90° than at 60° F. The initial drying phase, when evaporation was primarily a function of atmospheric stress, was followed by a transitional phase during which the drying rate decreased, apparently as a function of soil-moisture distribution. This was followed by a third phase during which evaporation continued at a nearly constant but much lower rate and appeared to be a function of heat flux. The change from the first through the second and to the third phase was relatively abrupt in sandy soils in comparison with the clay. The transition from the first to the second phase occurred at a slightly lower moisture content at 90° than at 60°F. A considerably greater percentage of moisture was lost from the sandy soils than from the clay before they passed from the first phase into the second, and more time was required. This was particularly



evident in the fall run. These data fit the concept of evaporation from bare soil discussed by Philip (1964) and Gardner and Hillel (1962).

The percentage of applied water which evaporated was fitted to the model:

$$Y = Ae^{-B/t} \quad [1]$$

where

$Y$  = percentage of water evaporated

$t$  = time in days

$B$  = drying time lag coefficient

$A$  = the ultimate equilibrium drying moisture content

Values of  $A$  and  $B$  for the six soils and correlation coefficients under three drying conditions are shown in table 2. Ideally,  $A$  values should be 100 percent. This point was not actually reached under diurnally fluctuating atmospheric conditions, however, even after many weeks of drying. The rate of change of drying may be expressed mathematically by the differential equation:

$$\frac{dY}{dt} = \frac{BAe^{-B/t}}{t^2} = \frac{BY}{t^2} \quad [2]$$

Table 2.--Values of A and B in equation 1, and regression coefficients for each of six Rio Puerco soils under drying conditions. Santa Fe, New Mexico, 1968

Soils	May-June, 90°F.			May-June, 60°F.			Aug.-Oct., 60°F.		
	A	B	r	A	B	r	A	B	r
Br	95.47	2.778	0.998	90.30	4.275	0.994	86.60	5.916	0.982
Pf	99.94	2.959	.996	96.24	5.008	.992	96.30	7.790	.979
Au	94.98	3.621	.997	88.84	5.624	.994	89.23	8.971	.985
Ps	81.73	3.175	.995	71.23	4.036	.997	69.15	6.552	.983
Cg	95.75	3.520	.997	89.47	5.676	.995	89.76	9.420	.985
Ng	80.70	3.582	.993	68.44	4.520	.997	75.03	9.146	.979

Thus rate of change of drying at any point in time may be calculated from the curves of figures 1-3.

With minor exceptions, the evaporation data fit the theoretical model quite well, as shown by the consistently high correlation coefficients. Some adjustment downward should be made, because the curves are made to pass through the origin.

Atmospheric conditions (wind, temperature, and radiation) markedly affected evaporation rate, particularly when the soils were wet. The initial rate of water loss in mid-May from the pots in the 60° F. water bath was about double the rates from the same pots and bath in late August through October, when daily atmospheric stresses were appreciably less.

Some evidence of soil structural change was apparent between the curves in figures 1 and 3 for the Persayo and Navajo soils. The Navajo clay shrunk and cracked appreciably upon drying and tended to aggregate, while the Persayo soil did not. The result was a convergence of the drying curves of the two soils in the second run. This phenomenon of changing structure with successive wetting and drying was discussed by Gardner and Hanks (1966).

### Laboratory Drying Experiment

**Procedure.**—The second experiment was run in the laboratory with the same six soils. Samples were passed through a crusher to break down clods, and were then placed in plastic-lined containers 6 inches in diameter by 4 inches deep. Twenty-five hundred grams of air-dry soil was placed in each

container. Each of the six soils was replicated four times.

The temperature in the laboratory was maintained at 83° F.  $\pm$  3° with a fan to increase air circulation.

Successive applications of 0.1, 0.2, 0.5, and 1 inch of water were added to all pots and allowed to evaporate.

**Results.**—When increments of 0.1, 0.2, and 0.5 inch of water were applied to the surface of the six soils, differences in evaporation rates among soils were negligible (fig. 4). With the exception of the 1-inch application, the differences in evaporative loss among soils were not statistically significant until over half of the applied water was gone, as measured by an analysis of variance of periodic accumulative moisture loss. The Navajo soil showed a tendency to dry more slowly than the other five soils. At the same time, the sandy soils, Berent and Penistaja, lost their moisture more quickly than those with finer texture, although the variation was slight. However, differences between these two soils and the others were large only from the 1-inch application. It appears that evaporative demand was the primary controlling energy factor when small increments of water were added, and moisture transmission and heat flux were minor or negligible. With the 1-inch application, effects of moisture transmission and possibly heat flux increased.

Under these mild stress conditions, approximately half the 0.1, 0.2, and 0.5 inch increments of water evaporated from all pots in 8, 24, and 72 hours, respectively. When 1 inch of water was applied,

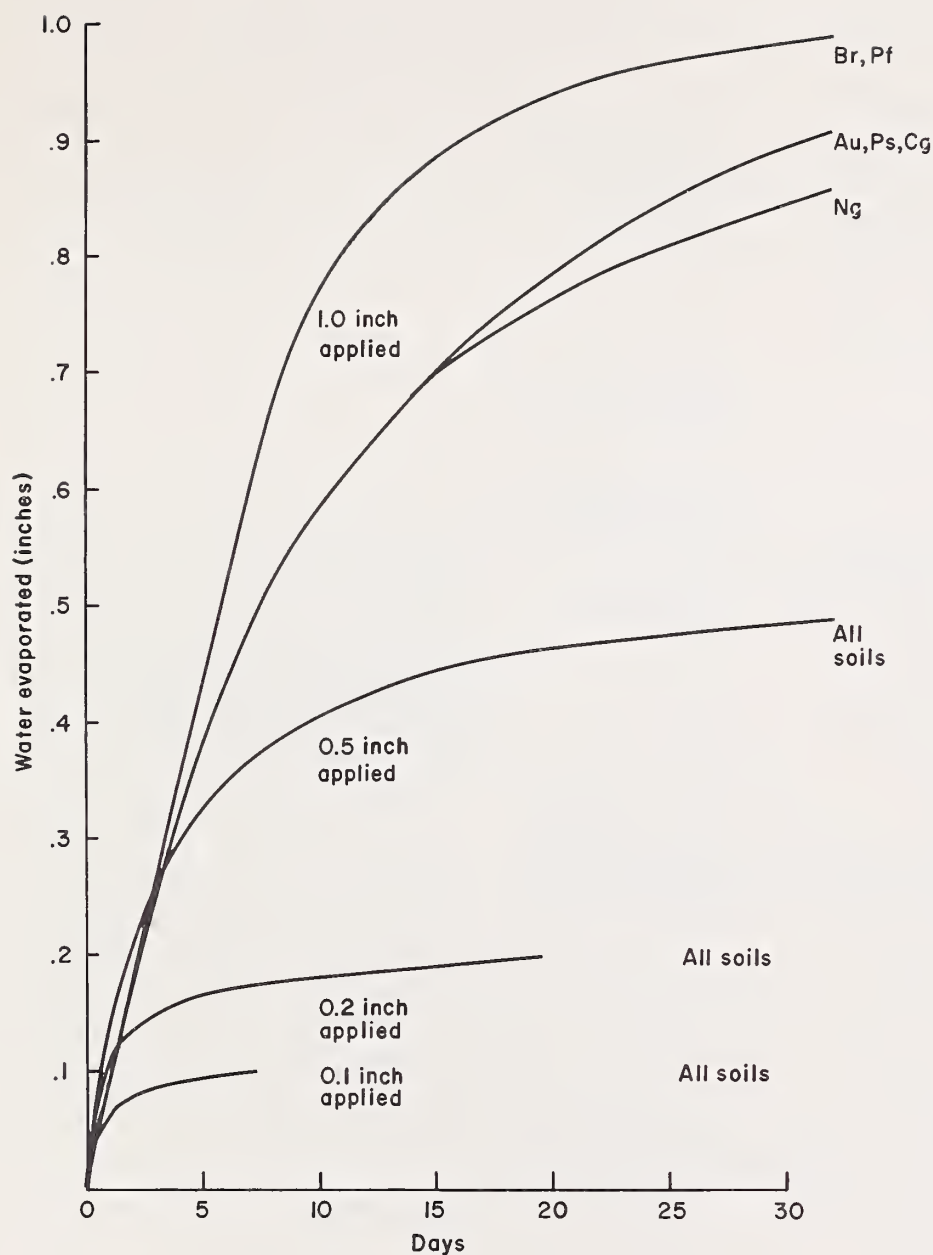


Figure 4.--Inches of water evaporated from six soils to which had been applied 0.1, 0.2, 0.5, and 1 inch of water. Soils were on laboratory table at 83°F.

about half of it evaporated in 4.5 days from the sandy soils compared to 7 days for the finer textured soils.

#### Roof Experiment

**Procedure.**—In a third experiment, Penistaja, Christianburg, and Navajo soils were potted in containers used in the second experiment. Water was added in 0.5-, 1.0-, and 1.5-inch increments. Each of these water-soil treatments was replicated three times. The pots were then exposed to the atmosphere on a graveled roof from May 26 to June 6, where the daily maximum and minimum temperatures averaged 91° and 59° F., respectively.

**Results.**—Evaporation curves for two soils only are shown (fig. 5). When 0.5 inch of water was added, the evaporation curves of the two soils (Penistaja loam and Navajo clay) were very similar. Differences in evaporation from the two soils increased as the amount of water applied increased, which indicates an increasing effect of soil moisture transmission and heat flux as the increment of applied water increased.

#### Discussion

Data from these studies indicate that evaporation from soil was strongly influenced by soil temperature. When soils were held at 60° F., water from wet soil

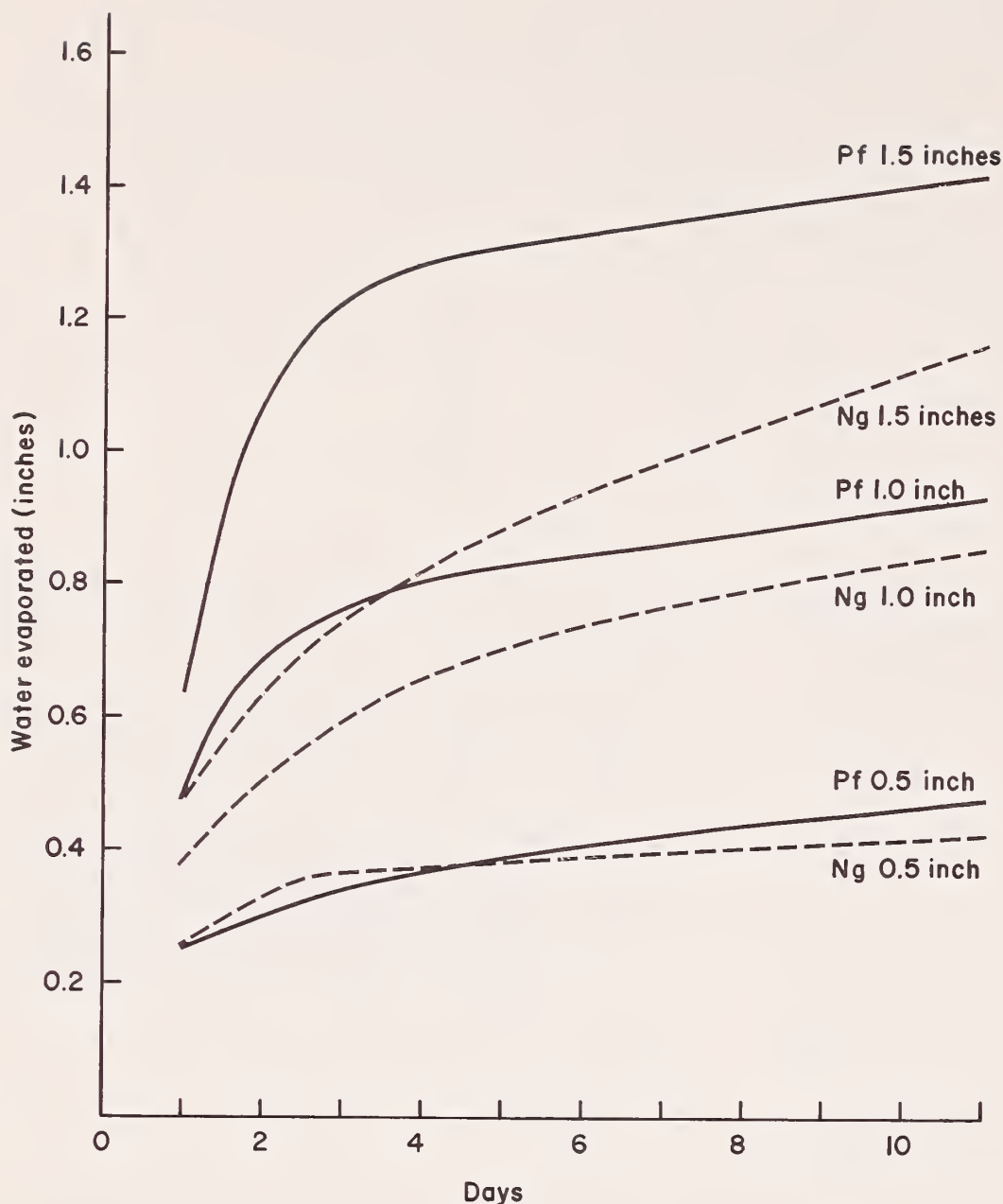


Figure 5.--Inches of water evaporated from two soils to which had been applied 0.5, 1.0, and 1.5 inches of water. Soils were exposed to open atmosphere with average daily maximum temperature of 93°F. and daily minimum of 59°F.

(first week of drying from saturated) evaporated at 0.22 inch per day as compared to 0.33 inch per day from soil held at 90° F.

Evaporation rates were also strongly influenced by atmospheric conditions, including air temperature, wind, and radiation. Although these factors were not documented, day-to-day fluctuations in weather had a noticeable effect on evaporation. Soils in the 60° F. bath lost water by evaporation almost twice as rapidly in May-June as in August-September-October.

When soils were saturated, sandy soils lost half their moisture by evaporation in 5 days at 90°F. and 7 days at 60°F. compared to 8 and 15 days for Navajo clay under similar conditions.

Interpretation of the data is complicated by complex environmental conditions and by the limited

data. Moisture profiles were not followed as drying progressed, so only limited interpretation of successive soil weights is possible.

In the first drying of soils from saturation, -1/3 bar mean potential was reached (using equation 1) in the Navajo clay in 4.3 days at 90° F. and in 6.5 days at 60°F. On the other extreme, the Penistaja sandy loam reached -1/3 bar potential in 10 days at 90° F. and 19.3 days at 60° F. The other soils ranged between these extremes.

If equation 2 is applied to these points, the Penistaja soil was losing 2.1 percent of applied moisture per day at 90°F. and 1.0 percent per day at 60°F.; Navajo clay was losing 6.6 percent per day at 90° F. and 3.6 percent per day at 60° F. The implication of these calculations is that sandy soils lose moisture from the surface rather rapidly

in comparison to clay, but a moisture barrier is formed by the dried surface soils, and the sub-surface potential changes more slowly than in the clay.

These findings are limited in field application to situations where there is negligible internal drainage. If the internal drainage were unrestricted, the sandy soils would reach -1/3 bar potential more quickly than the clay.

Although the rate of moisture loss was less from the sandy soils at -1/3 bar than from the clay at the same mean potential, the sandy soil had only 4 percent moisture by weight to lose before reaching the -15 bar potential, whereas the clay soil had 19 percent more moisture by weight at -1/3 bars than at -15 bars.

Initial evaporation rates were nearly the same for all these soils when small increments of water were applied. By the time half of a 1-inch application had evaporated, however, considerably lower evaporation rates were evident in the finer-textured soils than in the sandy soils.

Here again the differences among soils are attributable to energy relations. The clay soils, because of their greater water-holding capacity, held that water with greater force than did the sandy soils. For example, 1 inch of water was more than enough to wet the entire container of Penistaja fine sandy loam, but only wet the Navajo soil to about 1.8 inches deep. Upon drying (fig. 5) the Penistaja soil reached -15 bars potential in 4 days, as compared to 2 days for the wetted portion of the Navajo clay. Half an inch of water wet the entire container of Penistaja, but wet the Navajo clay only to 0.9 inch. The Penistaja sandy loam soil dried to -15 bars potential in 2 days, while the wetted Navajo clay reached -15 bars potential in less than 1 day.

These projections gain relevance when we consider that the average summer convective storm at the San Luis experimental watershed deposits less than 0.3 inch of water. A storm which precipitates over 1.5 inches occurs about once every 2 years. These large storms often occur in the fall

and extend over a 2-day period.<sup>2</sup> Sufficient time usually elapses between the summer storms for the soil to dry out.

On the basis of these studies and in view of the prevailing weather patterns, it becomes evident that the amount of moisture received from precipitation alone is not enough to maintain adequate soil moisture conditions for range grass germination and seedling establishment. Additional moisture contributed as runoff from adjacent areas is required.

### Literature Cited

- Folks, James J. and Walter B. Stone.  
1968. Soil survey of Cabezon area, New Mexico. USDA Soil Conserv. Serv. and USDI Bur. Land Manage., 44 p.
- Gardner, H. R. and R. J. Hanks.  
1966. Effect of sample size and environmental conditions on evaporation of water from soil. USDA Conserv. Res. Rep. 9, 14 p. Agr. Res. Serv. in cooperation with Colo. Agr. Exp. Sta., Fort Collins, Colo.
- Gardner, W. R.  
1961. Soil water relations in arid and semi-arid conditions. *Arid Zone Res.* 15: 37-61.
- Gardner, W. R. and D. I. Hillel.  
1962. The relation of external evaporative conditions to the drying of soils. *J. Geophys. Res.* 67: 4319-4325.
- Hanks, R. J., A. Klute, and E. Bresler.  
1969. A numeric method of estimating infiltration, redistribution, drainage, and evaporation of water from soil. *Water Resour. Res.* 5: 1064-1069.
- Philip, J. R.  
1964. The gain, transfer, and loss of soil-water. In *Water Resources, Use and Management*, C-1, p. 257-275. Melbourne Univ. Press, Melbourne, Aust.

<sup>2</sup> *Unpublished data. Rocky Mountain Forest and Range Exp. Sta., Albuquerque.*

NATIONAL AGRICULTURAL LIBRARY



1023085825